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AUTONOMIC METHOD AND APPARATUS FOR LOCAL PROGRAM CODE REORGANIZATION USING BRANCH COUNT PER INSTRUCTION HARDWARE

CROSS REFERENCE TO RELATED APPLICATIONS

The present invention is related to the following applications entitled "Method and Apparatus for Counting Instruction Execution and Data Accesses", serial no. __________, attorney docket no. AUS920030477US1, filed on September 30, 2003; "Method and Apparatus for Selectively Counting Instructions and Data Accesses", serial no. __________, attorney docket no. AUS920030478US1, filed on September 30, 2003; "Method and Apparatus for Generating Interrupts Upon Execution of Marked Instructions and Upon Access to Marked Memory Locations", serial no. __________, attorney docket no. AUS920030479US1, filed on September 30, 2003; "Method and Apparatus for Counting Data Accesses and Instruction Executions that Exceed a Threshold", serial no. __________, attorney docket no. AUS920030480US1, filed on September 30, 2003; "Method and Apparatus for Counting Execution of Specific Instructions and Accesses to Specific Data Locations", serial no. __________, attorney docket no. AUS920030481US1, filed on September 30, 2003; "Method and Apparatus for Debug Support for Individual Instructions and Memory Locations", serial no. __________, attorney docket no. AUS920030482US1, filed on September 30, 2003; "Method and Apparatus to Autonomically Select Instructions for Selective Counting", serial no. __________, attorney

docket no. AUS920030483US1, filed on September 30, 2003; "Method and Apparatus to Autonomically Count Instruction Execution for Applications", serial no. __________, attorney docket no. AUS920030484US1, filed on September 30, 2003; "Method and Apparatus to Autonomically Take an Exception on Specified Instructions", serial no. __________, attorney docket no. AUS920030485US1, filed on September 30, 2003; "Method and Apparatus to Autonomically Profile Applications", serial no. __________, attorney docket no. AUS920030486US1, filed on September 30, 2003; "Method and Apparatus for Counting Instruction and Memory Location Ranges", serial no. __________, attorney docket no. AUS920030487US1, filed on September 30, 2003; "Autonomic Method and Apparatus for Counting Branch Instructions to Improve Branch Predictions", serial no. __________, attorney docket no. AUS920030550US1, filed on __________; and "Autonomic Method and Apparatus for Hardware Assist for Patching Code", serial no. __________, attorney docket no. AUS920030551US1, filed on __________. All of the above related applications are assigned to the same assignee, and incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Technical Field:

The present invention relates generally to an improved data processing system and, in particular, to a method and system for improving performance of the processor in a data processing system. Still more particularly, the present invention relates to a method, apparatus, and computer instructions for local code reorganization using branch count per instruction hardware.

2. Description of Related Art:

In a computer system, branch prediction is a technique used to guess whether a conditional branch will be taken or not. If it is predicted that a conditional branch will be taken, the processor will prefetch code for the branch instruction from the appropriate location. A speculative execution is performed to take advantage of branch prediction by executing the instruction before the processor is certain that they are in the correct execution path. For example, if a branch is taken more than 90 percent of the time, it is predicted to be taken and the processor will prefetch the code prior to reaching the branch instruction.

A branch instruction may be conditional or unconditional. A conditional branch instruction causes an instruction to branch or jump to another location of code if a specified condition is satisfied. If the

condition is not satisfied, the next instruction in sequential order is fetched and executed.

A special fetch/decode unit in a processor uses a branch prediction algorithm to predict the direction and outcome of the instructions being executed through multiple levels of branches, calls, and returns. Branch prediction enables the processor to keep the instruction pipeline full while running at a high rate of speed. In conventional computer systems, branch prediction is based on branch prediction software that uses branch statistics and other data to minimize stalls caused by delays in fetching instructions that branch to nonlinear memory locations.

In some cases, the code of a program can be locally reorganized to improve performance. Such code reorganization is typically based on software generated statistics to determine whether local code reorganization is advantageous. However, such software generated statistics require use of resources that may in some cases be better allocated to other tasks, while hardware resources that may be present go unused, resulting in an inefficient use of overall resources.

Therefore, it would be advantageous to have an improved method, apparatus, and computer instructions for providing branch count per instruction statistics that allow a program to autonomically perform local code reorganization, so that processor performance may be optimized.

SUMMARY OF THE INVENTION

The present invention provides a method, apparatus, and computer instructions for local program code reorganization at run time using branch count per instruction hardware. In a preferred embodiment, the mechanism of the present invention allows a program to analyze branch count per instruction statistics generated using hardware counters. The branch count per instruction statistics identify the number of times a branch is actually taken when a branch instruction is executed.

Based on the branch count per instruction statistics, the program autonomically determines whether the code requires reorganization in order to optimize processor performance. The program may reorganize the code by swapping location of an "if/then/else" statement locally so that more instructions may be executed contiguously prior to taking the branch. This run time code reorganization minimizes the number of branches taken without modifying the underlying application code.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

Figure 1 is an exemplary block diagram of a data processing system in which the present invention may be implemented;

Figure 2 is an exemplary block diagram of a processor system for processing information in accordance with a preferred embodiment of the present invention;

Figure 3A is an exemplary diagram illustrating example branch statistic fields in accordance with a preferred embodiment of the present invention;

Figure 3B is an exemplary diagram illustrating an example branch instruction in accordance with a preferred embodiment of the present invention;

Figure 4 is an exemplary diagram illustrating an example meta data in accordance with a preferred embodiment of the present invention;

Figure 5 is an exemplary diagram illustrating program code reorganization by swapping "if", "then", "else" statements at run time in accordance with a preferred embodiment of the present invention; and

Figure 6 is a flowchart process outlining an exemplary process for local program code reorganization using branch count per instruction hardware at run time in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention provides a method, apparatus, and computer instructions for local program code reorganization at run time using branch count per instruction hardware. The present invention provides hardware counters to count the number of times a branch is actually taken when a branch instruction is executed.

The present invention may be implemented in a computer system. The computer system may be a client or a server in a client-server environment that is interconnected over a network. With reference now to **Figure 1**, an exemplary block diagram of a data processing system is shown in which the present invention may be implemented. Client **100** is an example of a computer, in which code or instructions implementing the processes of the present invention may be located. Client **100** employs a peripheral component interconnect (PCI) local bus architecture. Although the depicted example employs a PCI bus, other bus architectures such as Accelerated Graphics Port (AGP) and Industry Standard Architecture (ISA) may be used. Processor **102** and main memory **104** are connected to PCI local bus **106** through PCI bridge **108**. PCI bridge **108** also may include an integrated memory controller and cache memory for processor **102**. Additional connections to PCI local bus **106** may be made through direct component interconnection or through add-in boards. In the depicted example, local area network (LAN) adapter **110**, small computer system interface SCSI host bus adapter **112**, and expansion bus interface **114** are connected to PCI local bus

106 by direct component connection. In contrast, audio adapter **116**, graphics adapter **118**, and audio/video adapter **119** are connected to PCI local bus **106** by add-in boards inserted into expansion slots. Expansion bus interface **114** provides a connection for a keyboard and mouse adapter **120**, modem **122**, and additional memory **124**. SCSI host bus adapter **112** provides a connection for hard disk drive **126**, tape drive **128**, and CD-ROM drive **130**. Typical PCI local bus implementations will support three or four PCI expansion slots or add-in connectors.

An operating system runs on processor **102** and is used to coordinate and provide control of various components within data processing system **100** in **Figure 1**. The operating system may be a commercially available operating system such as Windows XP, which is available from Microsoft Corporation. An object oriented programming system such as Java may run in conjunction with the operating system and provides calls to the operating system from Java programs or applications executing on client **100**. "Java" is a trademark of Sun Microsystems, Inc. Instructions for the operating system, the object-oriented programming system, and applications or programs are located on storage devices, such as hard disk drive **126**, and may be loaded into main memory **104** for execution by processor **102**.

Those of ordinary skill in the art will appreciate that the hardware in **Figure 1** may vary depending on the implementation. Other internal hardware or peripheral devices, such as flash read-only memory (ROM), equivalent nonvolatile memory, or optical disk drives and the like,

may be used in addition to or in place of the hardware depicted in **Figure 1**. Also, the processes of the present invention may be applied to a multiprocessor data processing system.

For example, client **100**, if optionally configured as a network computer, may not include SCSI host bus adapter **112**, hard disk drive **126**, tape drive **128**, and CD-ROM **130**. In that case, the computer, to be properly called a client computer, includes some type of network communication interface, such as LAN adapter **110**, modem **122**, or the like. As another example, client **100** may be a stand-alone system configured to be bootable without relying on some type of network communication interface, whether or not client **100** comprises some type of network communication interface. As a further example, client **100** may be a personal digital assistant (PDA), which is configured with ROM and/or flash ROM to provide non-volatile memory for storing operating system files and/or user-generated data. The depicted example in **Figure 1** and above-described examples are not meant to imply architectural limitations.

The processes of the present invention are performed by processor **102** using computer implemented instructions, which may be located in a memory such as, for example, main memory **104**, memory **124**, or in one or more peripheral devices **126-130**.

Turning next to **Figure 2**, an exemplary block diagram of a processor system for processing information is depicted in accordance with a preferred embodiment of the

present invention. Processor **210** may be implemented as processor **102** in **Figure 1**.

In a preferred embodiment, processor **210** is a single integrated circuit superscalar microprocessor. Accordingly, as discussed further herein below, processor **210** includes various units, registers, buffers, memories, and other sections, all of which are formed by integrated circuitry. Also, in the preferred embodiment, processor **210** operates according to reduced instruction set computer ("RISC") techniques. As shown in **Figure 2**, system bus **211** is connected to a bus interface unit ("BIU") **212** of processor **210**. BIU **212** controls the transfer of information between processor **210** and system bus **211**.

BIU **212** is connected to an instruction cache **214** and to data cache **216** of processor **210**. Instruction cache **214** outputs instructions to sequencer unit **218**. In response to such instructions from instruction cache **214**, sequencer unit **218** selectively outputs instructions to other execution circuitry of processor **210**.

In addition to sequencer unit **218**, in the preferred embodiment, the execution circuitry of processor **210** includes multiple execution units, namely a branch unit **220**, a fixed-point unit A ("FXUA") **222**, a fixed-point unit B ("FXUB") **224**, a complex fixed-point unit ("CFXU") **226**, a load/store unit ("LSU") **228**, and a floating-point unit ("FPU") **230**. FXUA **222**, FXUB **224**, CFXU **226**, and LSU **228** input their source operand information from general-purpose architectural registers ("GPRs") **232** and fixed-point rename buffers **234**. Moreover, FXUA **222** and FXUB **224**

input a "carry bit" from a carry bit ("CA") register **239**. FXUA **222**, FXUB **224**, CFXU **226**, and LSU **228** output results (destination operand information) of their operations for storage at selected entries in fixed-point rename buffers **234**. Also, CFXU **226** inputs and outputs source operand information and destination operand information to and from special-purpose register processing unit ("SPR unit") **237**.

FPU **230** inputs its source operand information from floating-point architectural registers ("FPRs") **236** and floating-point rename buffers **238**. FPU **230** outputs results (destination operand information) of its operation for storage at selected entries in floating-point rename buffers **238**.

In response to a Load instruction, LSU **228** inputs information from data cache **216** and copies such information to selected ones of rename buffers **234** and **238**. If such information is not stored in data cache **216**, then data cache **216** inputs (through BIU **212** and system bus **211**) such information from a system memory **239** connected to system bus **211**. Moreover, data cache **216** is able to output (through BIU **212** and system bus **211**) information from data cache **216** to system memory **239** connected to system bus **211**. In response to a Store instruction, LSU **228** inputs information from a selected one of GPRs **232** and FPRs **236** and copies such information to data cache **216**.

Sequencer unit **218** inputs and outputs information to and from GPRs **232** and FPRs **236**. From sequencer unit **218**, branch unit **220** inputs instructions and signals

indicating a present state of processor **210**. In response to such instructions and signals, branch unit **220** outputs (to sequencer unit **218**) signals indicating suitable memory addresses storing a sequence of instructions for execution by processor **210**. In response to such signals from branch unit **220**, sequencer unit **218** inputs the indicated sequence of instructions from instruction cache **214**. If one or more of the sequence of instructions is not stored in instruction cache **214**, then instruction cache **214** inputs (through BIU **212** and system bus **211**) such instructions from system memory **239** connected to system bus **211**.

In response to the instructions input from instruction cache **214**, sequencer unit **218** selectively dispatches the instructions to selected ones of execution units **220**, **222**, **224**, **226**, **228**, and **230**. Each execution unit executes one or more instructions of a particular class of instructions. For example, FXUA **222** and FXUB **224** execute a first class of fixed-point mathematical operations on source operands, such as addition, subtraction, ANDing, ORing and XORing. CFXU **226** executes a second class of fixed-point operations on source operands, such as fixed-point multiplication and division. FPU **230** executes floating-point operations on source operands, such as floating-point multiplication and division.

As information is stored at a selected one of rename buffers **234**, such information is associated with a storage location (e.g. one of GPRs **232** or carry bit(CA) register **242**) as specified by the instruction for which

the selected rename buffer is allocated. Information stored at a selected one of rename buffers **234** is copied to its associated one of GPRs **232** (or CA register **242**) in response to signals from sequencer unit **218**. Sequencer unit **218** directs such copying of information stored at a selected one of rename buffers **234** in response to "completing" the instruction that generated the information. Such copying is called "writeback."

As information is stored at a selected one of rename buffers **238**, such information is associated with one of FPRs **236**. Information stored at a selected one of rename buffers **238** is copied to its associated one of FPRs **236** in response to signals from sequencer unit **218**. Sequencer unit **218** directs such copying of information stored at a selected one of rename buffers **238** in response to "completing" the instruction that generated the information.

Processor **210** achieves high performance by processing multiple instructions simultaneously at various ones of execution units **220**, **222**, **224**, **226**, **228**, and **230**. Accordingly, each instruction is processed as a sequence of stages, each being executable in parallel with stages of other instructions. Such a technique is called "pipelining." In a significant aspect of the illustrative embodiment, an instruction is normally processed as six stages, namely fetch, decode, dispatch, execute, completion, and writeback.

In the fetch stage, sequencer unit **218** selectively inputs (from instruction cache **214**) one or more instructions from one or more memory addresses storing

the sequence of instructions discussed further hereinabove in connection with branch unit **220**, and sequencer unit **218**. In the decode stage, sequencer unit **218** decodes up to four fetched instructions.

In the dispatch stage, sequencer unit **218** selectively dispatches up to four decoded instructions to selected (in response to the decoding in the decode stage) ones of execution units **220**, **222**, **224**, **226**, **228**, and **230** after reserving rename buffer entries for the dispatched instructions' results (destination operand information). In the dispatch stage, operand information is supplied to the selected execution units for dispatched instructions. Processor **210** dispatches instructions in order of their programmed sequence.

In the execute stage, execution units execute their dispatched instructions and output results (destination operand information) of their operations for storage at selected entries in rename buffers **234** and rename buffers **238** as discussed further hereinabove. In this manner, processor **210** is able to execute instructions out-of-order relative to their programmed sequence.

In the completion stage, sequencer unit **218** indicates an instruction is "complete." Processor **210** "completes" instructions in order of their programmed sequence.

In the writeback stage, sequencer **218** directs the copying of information from rename buffers **234** and **238** to GPRs **232** and FPRs **236**, respectively. Sequencer unit **218** directs such copying of information stored at a selected rename buffer. Likewise, in the writeback stage of a

particular instruction, processor **210** updates its architectural states in response to the particular instruction. Processor **210** processes the respective "writeback" stages of instructions in order of their programmed sequence. Processor **210** advantageously merges an instruction's completion stage and writeback stage in specified situations.

In the illustrative embodiment, each instruction requires one machine cycle to complete each of the stages of instruction processing. Nevertheless, some instructions (e.g., complex fixed-point instructions executed by CFXU **226**) may require more than one cycle. Accordingly, a variable delay may occur between a particular instruction's execution and completion stages in response to the variation in time required for completion of preceding instructions.

Completion buffer **248** is provided within sequencer **218** to track the completion of the multiple instructions which are being executed within the execution units. Upon an indication that an instruction or a group of instructions have been completed successfully, in an application specified sequential order, completion buffer **248** may be utilized to initiate the transfer of the results of those completed instructions to the associated general-purpose registers.

In addition, processor **210** also includes performance monitor unit **240**, which is connected to instruction cache **214** as well as other units in processor **210**. Operation of processor **210** can be monitored utilizing performance monitor unit **240**, which in this illustrative embodiment

is a software-accessible mechanism capable of providing detailed information descriptive of the utilization of instruction execution resources and storage control. Although not illustrated in **Figure 2**, performance monitor unit **240** is coupled to each functional unit of processor **210** to permit the monitoring of all aspects of the operation of processor **210**, including, for example, reconstructing the relationship between events, identifying false triggering, identifying performance bottlenecks, monitoring pipeline stalls, monitoring idle processor cycles, determining dispatch efficiency, determining branch efficiency, determining the performance penalty of misaligned data accesses, identifying the frequency of execution of serialization instructions, identifying inhibited interrupts, and determining performance efficiency. The events of interest also may include, for example, time for instruction decode, execution of instructions, branch events, cache misses, and cache hits.

Performance monitor unit **240** includes an implementation-dependent number (e.g., 2-8) of counters **241-242**, labeled PMC1 and PMC2, which are utilized to count occurrences of selected events. Performance monitor unit **240** further includes at least one monitor mode control register (MMCR). In this example, two control registers, MMCRs **243** and **244** are present that specify the function of counters **241-242**. Counters **241-242** and MMCRs **243-244** are preferably implemented as SPRs that are accessible for read or write via MFSPR (move from SPR) and MTSPR (move to SPR) instructions executable by CFXU

226. However, in one alternative embodiment, counters **241-242** and MMCRs **243-244** may be implemented simply as addresses in I/O space. In another alternative embodiment, the control registers and counters may be accessed indirectly via an index register. This embodiment is implemented in the IA-64 architecture in processors from Intel Corporation. Counters **241-242** may also be used to collect branch statistics per instruction when a program is executed.

As described above, the present invention provides a method, apparatus, and computer instructions for local program code reorganization using branch count per instruction hardware. Program code reorganization may include reorganization of a single instruction or a set of instructions within a program, also known as a block of code. Instructions within a block of code may be contiguous or non-contiguous. The present invention provides hardware counter, such as counters **241** and **242** in **Figure 2**, to count the number of times a branch is taken when a branch instruction is executed.

In a preferred embodiment, the present invention allows a program or application to autonomically determine whether program code should be reorganized at run time by examining the branch count per instruction statistics provided by hardware counters. If code is to be reorganized, the performance monitoring program can use various techniques to halt execution of the instructions and then reorganizes the code by swapping instructions. Instruction is halted, for example, by causing a branch to branch to itself until modification

of the code is complete, in order to ensure that the processor has stopped executing the code that is to be modified. When the relevant code has been modified and can be safely executed, the branch to self is removed and normal execution resumes. This mechanism allows a program to interrupt a normal execution and reorganize program code at run time.

Turning to **Figure 3A**, an exemplary diagram illustrating example branch statistic fields is depicted in accordance with a preferred embodiment of the present invention. In this illustrative example, there are three branch statistic fields, shown as branch field **302**, branch prediction field **304**, and branch count field **306** associated with a branch instruction. These branch statistics fields may be stored in a separate area of storage, such as performance instrumentation shadow cache. Performance instrumentation shadow cache may be implemented using any storage device, such as, for example, a system memory, a flash memory, a cache, or a disk. Branch field **302** indicates whether a branch is taken or not last time the branch instruction is executed. Branch prediction field **304** indicates the branch prediction made based on the branch count. There may be three values associated with the branch prediction field. A value of "00" indicates that no previous data is collected for the branch instruction. A value of "01" indicates a branch is predicted to be taken for the branch instruction, and a value of "02" indicates a branch is predicted to be not taken for the branch instruction. Branch prediction is normally performed

before the branch is executed. Branch count field **306** indicates the number of times a branch is taken when the branch instruction is executed. Hardware counters increment or decrement this field based on whether a branch is taken or not when the branch instruction is executed.

With reference to **Figure 3B**, an exemplary diagram illustrating an example branch instruction is depicted in accordance with a preferred embodiment of the present invention. As depicted in **Figure 3B**, branch instruction **310** is associated with two different meta data, meta data **312** and redirection address field **314**. Meta data **312** represents the branch statistics fields as described in **Figure 3A**, which is associated with branch instruction **310**. Redirection address field **314** indicates that meta data is associated with branch instruction **310**.

With reference now to **Figure 4**, an exemplary diagram illustrating an example meta data is depicted in accordance with a preferred embodiment of the present invention. In this illustrative example, meta data **402** may be stored in a dedicated memory location where it is accessible to the processor. Meta data **402** includes two pointers. One pointer points to the starting address of the reorganized code block **404**. Another pointer points to the address of the instruction following the branch instructions in the original code **406**. Pointer **404** is examined by the processor when a branch instruction associated with meta data, such as redirection address field **314** in **Figure 3B**, is executed. Pointer **506** is

examined by the processor when execution of the reorganized instruction is complete.

In a preferred embodiment, the present invention allows a program to swap the location of the "then", and "else" statements of an "if/then/else" statement within the program at run time based on the branch count per instruction statistics provided by hardware counters. An "if" statement specifies a condition that is examined when a branch instruction is executed. A "then" statement is an instruction that is executed when the "if" condition is satisfied. An "else" statement is an instruction that is executed when the "if" condition is not satisfied. Typically, an "else" statement follows the branch instruction in the normal execution sequence. For example, if the program determines that code should be reorganized at run time, the program may swap the location of "then" with the "else" statements, in order to allow more instructions to be executed contiguously before a branch is taken.

Such swapping of then/else statements also requires modification of the condition. For example, in a simple case with a single condition "Value1 greater than 0," the "then" statement would execute if Value1 is greater than zero, and the "else" statement would execute if Value1 is not greater than zero. Hence, swapping the "then" and "else" statements would also require that the condition "Value1 greater than 0" be modified to "Value1 less than or equal to 0." In this way, the "then" statement will be executed under the same conditions as prior to code modification, and likewise with the "else" statement.

Turning next to **Figure 5**, an exemplary diagram illustrating program code reorganization by swapping "then" and "else" statements at run time is depicted in accordance with a preferred embodiment of the present invention. In this illustrative example, program **502** examines "if" condition **504** to check if the value in register R1 is not equal to zero. If "if" condition **504** is satisfied, a comparison is made by cmp instruction **506** to compare the value of register R1 and 0. If the value of register R1 is equal to 0, jmpe instruction **508** jumps to code block label 1 **510**. Code block label 1 **510**, which is the "else" statements, includes instructions 2, 3, 4, and 5. If the value of register R1 is not equal to 0, instruction 1 **512**, which is the "then" statement, is executed. Regardless of whether the "then" or the "else" statements are executed, code block label 2 **516** is executed. Code block label 2 **516** includes instructions 6, 7, 8, 9, 10 and return. Code block level 2 **516** is common to either condition.

By examining the branch count per instruction statistics provided by the hardware counters of the present invention, such as branch field **302** and branch prediction field **304** derived from the branch count field **306** as described in **Figure 3**, program **502** may notice that code block label 1 **510** is executed in multiple executions, which makes code block label 1 **510** a "hot spot". Thus, program **502** may reorganize the location of code block label 1 **510** instructions at run time and the reorganized program is shown as program **520** in **Figure 5**.

Program **520** includes the same "if" condition **522** and cmp instruction **524**. However, the condition of jmpe instruction **508** is modified to become a jmpne instruction **526**. Jmpne instruction **526** jumps to code block label 2 **528** only if the value of register R1 is not equal to 0. Instructions 2, 3, 4, and 5 **530** that are originally located in code block label 1 **510** are now relocated to be executed after jumpne instruction **526** to allow more contiguous code to be executed in sequence. Code block level 2 **516** that is common to either condition is also relocated to code block label 1 **532**, which is executed after instructions 2, 3, 4 and 5 **530** contiguously.

Notice that the "else" condition **540** in program **502** is no longer required, since modifying the condition of jmpe statement **508** (jump if equal) to jmpne statement **526** (jump if not equal) in program **520** and relocating instructions 2, 3, 4 and 5 **530** to be executed after jmpne instruction **526** allows "else" statements **530** to be executed right after the comparison is made.

Thus, by swapping the locations of "then" statements **512** and "else" statements **510** and modifying the condition of jmpe statement **508**, program **520** allows more instructions to be executed contiguously because "else" instructions **530** are now located closer to "if" condition **522**.

Turning next to **Figure 6**, a flowchart process outlining an exemplary process for local program code reorganization using branch count per instruction hardware at run time is depicted in accordance with a preferred embodiment of the present invention. In this

example illustration, the process begins when a CPU executes program instructions in execution sequence (step **602**). The CPU then looks ahead and sees a branch instruction (step **604**). Next, the program analyzes branch count per instruction statistics provided by the hardware counters (step **606**) by examining the branch count field associated with the instruction. Based on the number of times a branch is taken, a determination is made by the program whether or not to reorganize code (step **608**). If the program determines not to reorganize code, the processor continues to execute normal program instructions following the normal execution sequence (step **610**), the process terminating thereafter.

If the program determines to reorganize code, the program notifies the processor to halt execution of instructions (step **612**) and swap the locations of the "then" and "else" statements such that more instructions are executed contiguously (step **614**). Note that this step preferably includes modifying the condition of the "if" statement as well, such that the "then" instruction occurs under the same circumstances as before modification, as well as the "else" statement, as described above. Once the reorganization is complete, the program notifies the processor to restart execution of instructions (step **616**) and the processor continues to execute normal program instructions following the normal execution sequence (step **610**), the process terminating thereafter.

Thus, the present invention provides branch count per instruction hardware to count the number of times a branch is taken. Using branch count per instruction statistics generated by the hardware counters, the program may determine whether or not to reorganize code locally at run time. A program may autonomically reorganize code by swapping the branch instruction with other instructions to optimize program performance. In an alternative embodiment, a program may swap the locations of the "then" and "else" statements (as well as changing the condition) to allow more instructions to be executed contiguously before taking a branch. Thus, the number of branches taken is minimized without modifying underlying program code.

It is important to note that while the present invention has been described in the context of a fully functioning data processing system, those of ordinary skill in the art will appreciate that the processes of the present invention are capable of being distributed in the form of a computer readable medium of instructions and a variety of forms and that the present invention applies equally regardless of the particular type of signal bearing media actually used to carry out the distribution. Examples of computer readable media include recordable-type media, such as a floppy disk, a hard disk drive, a RAM, CD-ROMs, DVD-ROMs, and transmission-type media, such as digital and analog communications links, wired or wireless communications links using transmission forms, such as, for example, radio frequency and light wave transmissions. The

computer readable media may take the form of coded formats that are decoded for actual use in a particular data processing system.

The description of the present invention has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. The embodiment was chosen and described in order to best explain the principles of the invention, the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.